

Weilun Chao

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EDUCATION

<u>University of California at Berkeley</u> , Berkeley, CA	2005
Ph.D., Electrical Engineering	
Dissertation: Resolution Characterization and Nanofabrication for Soft X-ray Zone Plate Microscopy	
<u>Stony Brook University</u> , Stony Brook, NY	1999
B.Eng. in Electrical Engineering, <i>Summa Cum Laude</i>	
B.S. in Physics, with Minor in Optics, <i>Summa Cum Laude and departmental honor</i>	

RESEARCH INTERESTS: optical microscopy, optical modeling, nanolithography and nanobiology

PROFESSIONAL EXPERIENCE

<u>Lawrence Berkeley National Laboratory</u>	
Research Scientist	2007-present

Design, develop and realize innovative techniques and technologies to advance the imaging performance of optical microscopy for life sciences and nanomaterials. Create mathematical models to simulate various optical and nanofabrication processes for x-ray optics. Explore innovative ideas to improve fabrication process yield for challenging nanostructures. Investigate the effects of the lens designs, light source and other optical components on imaging performance at the nanometer scale. Help manage laboratory operation, project prioritization, and strategy development of resource distribution within funding constraints.

Achievements

- Successfully improved the world's highest lateral resolution in optical microscopy to presently 12 nm.
- Developed an electron beam overlay nanofabrication process for 10 nm dense structures.
- Realized high-quality nanoscale optics and structures for diverse scientific and technological studies worldwide.
- Created a lithographic process for large optics and fabricated 1 cm diameter condenser optics with 30 nm features.

<u>University of California at Berkeley</u>	
Associate Researcher	2005-2007
Research Assistant	1999-2005

Developed extreme ultraviolet (EUV) table-top imaging systems for metrology applications. Established reliable resolution testing of x-ray optics. Fabricated high performance x-ray optics and test structures for biological and nanomagnetism studies.

Achievements

- Executed an award winning EUV microscope, EUVM-1, for ablation applications.
- Demonstrated the significance of partial coherence in full-field microscopy on lateral resolution using mathematical modeling of realistic imaging conditions.
- Optimized multilayer reflective optics designs critical to extreme ultraviolet lithography throughput.
- Successfully developed a lithographic process for stacking nanostructures in high accuracy.

AWARDS AND PATENTS

- The 2008 R&D 100 Award for Extreme Ultraviolet Light Table-Top Microscope (EUVM-1), a nano-imaging instrument developed in collaboration with the University of California, Berkeley and Colorado State University.
- The 2005 Prestigious Werner Meyer-Ilse Memorial Award for contributions to the development of X-ray microscopy: an individual award every three years.
- “Nanometer-scale ablation using focused, coherent extreme ultraviolet/soft x-ray light”, Filing date: August 2007, Application Number: 11/840,898, pending approval.

INVITED INTERNATIONAL PRESENTATIONS

- W. Chao, E.H. Anderson, P. Fischer, B. Harteneck, J.A. Liddle and D.T. Attwood, “Soft X-ray Zone Plate Microscopy to 10 nm Resolution with XM-1 at the ALS,” presented at the *9th International Conference on Synchrotron Radiation Instrumentation, May 28- June 2, 2006, Daegu, Korea*.
- W. Chao, B. Harteneck, J.A. Liddle, E.H. Anderson and D.T. Attwood, “Zone Plate Microscopy to sub-15 nm Spatial Resolution with XM-1 at the ALS,” presented at the *8th International Conference on X-ray Microscopy, July 26-30, 2005, Himeji, Japan*.

PUBLICATIONS

Featured Articles

1. W. Chao, E. Anderson, G. Denbeaux, B. Harteneck, J.A. Liddle, D. Olynick, A.L. Pearson, F. Salmassi, C. Song, and D. Attwood, “20-nm Spatial Resolution Photon-based Microscopy,” *selected to be in the microscopy category in “Optics in 2003,”* Opt. Photon. News **14**(12), 18 (2003).
2. P. Fischer, D.-H. Kim, W. Chao, J. A. Liddle, E. H. Anderson and D. T. Attwood, “Soft X-Ray Microscopy of Nanomagnetism,” Mater. Today **9**, 26-33 (2006).
3. G. Vaschenko, F. Brizuela, C. Brewer, M. Grisham, C.S. Menoni, M. Marconi, J.J. Rocca, W.L. Chao, J.A. Liddle, E.H. Anderson, D.T. Attwood, A.V. Vinogradov, I.A. Artioukov, Y.P. Pershyn and V.V. Kondratenko, “Nano-imaging with Compact Extreme Ultraviolet Lasers,” *selected to be in the imaging category in “Optics in 2005,”* Opt. Photon. News **16**(12), 25 (2005).

Journals and proceedings

2009

1. W. Chao, J. Kim, S. Rekawa, P. Fischer and E. Anderson, “Demonstration of 12 nm Resolution Fresnel Zone Plate Lens based Soft X-ray Microscopy,” Opt. Exp. **17**, 17669-17677 (2009).
2. W. Chao, J. Kim, S. Rekawa, P. Fischer and E. Anderson, “HSQ Double Patterning Process for 12 nm Resolution X-Ray Zone Plates,” J. Vac. Sci. Tech. B **27**, 2606-2611 (2009).
3. J. Kim, W. Chao, B. Griedel, X. Liang, M. Lewis, D. Hilken and D. Olynick, “Understanding the Mechanism of Base Development of HSQ,” J. Vac. Sci. Tech. B **27**, 2628-2634 (2009).
4. D. L. Olynick, P. Ashby, M. D. Lewis, T. Jen, H. Lu, J. A. Liddle and W. Chao, “The link between nanoscale feature development in a negative resist and the Hansen Solubility Sphere,” J. Polym. Phys. B **47**, 2091-2105 (2009).
5. S.-C. Gleber, J. Thieme, W. Chao and P. Fischer, “Stereo soft X-ray microscopy and elemental mapping of hematite and clay suspensions,” J. Microscopy **235**, 199-208 (2009).
6. F. Brizuela, Y. Wang, C. A. Brewer, F. Pedaci, W. Chao, E. H. Anderson, Y. Liu, K. A. Goldberg, P. Naulleau, P. Wachulak, M. C. Marconi, D. T. Attwood, J. J. Rocca, and C. S. Menoni, “Microscopy of extreme ultraviolet lithography masks with 13.2 nm tabletop laser illumination,” Opt. Lett. **34**, 271-273 (2009).

2008

7. W. Chao, E. H. Anderson, P. Fischer and D.-H. Kim, "Towards sub-10 resolution zone plates using the overlay nanofabrication processes," Proc. SPIE **6883**, p.688309 (2008).
8. C.A. Brewer, F. Brizuela, P. Wachulak, D.H. Martz, W. Chao, E.H. Anderson, D.T. Attwood, A.V. Vinogradov, I. Artyukov, A. Ponomareko, V. Kondratenko, M. Marconi, J. Rocca, and C. Menoni, "Single shot extreme ultraviolet laser imaging of nanostructures with wavelength resolution" Opt. Lett. **33**, 518-520 (2008).
9. P.W. Wachulak, C.A. Brewer, F. Brizuela, C.S. Menoni, W. Chao, E.H. Anderson, R. A. Bartels, J.J. Rocca, and M.C. Marconi, "Analysis of extreme ultraviolet microscopy images of patterned nanostructures based on a correlation method," J. Opt. Soc. Am. B **25**, B20-B26 (2008).

2007

10. M.G. Capelutoc, P. Wachulaka, M.C. Marconia D. Patela, C.S. Menonia, J.J. Roccaa, C. Iemmic, E.H. Anderson, W. Chao, and D.T. Attwood, "Table top nanopatterning with extreme ultraviolet laser illumination," Microelectron. Eng. **84**, 721-724 (2007).
11. B. Mesler, P. Fischer, W. Chao, E.H. Anderson and D.-Y. Kim, "Soft X-ray Imaging of Spin Dynamics at High Spatial and Temporal Resolution," J. Vac. Sci Tech. B, **25**, 2598-2602 (2007).
12. P. Fischer, D.-H. Kim, B.L. Mesler, W. Chao, A.E. Sakdinawat, and E.H. Anderson, "Exploring nanomagnetism with soft X-ray microscopy", Surface Sci. **601**, 4680-4685 (2007).
13. P. Fischer, D. H. Kim, B. L. Mesler, W. Chao, and E. H. Anderson, "Magnetic soft X-ray microscopy: Imaging spin dynamics at the nanoscale," J. Magn. Magn. Mat. **310**, 2689-2692 (2007).

2006

14. W. Chao, B. D. Harteneck, E. H. Anderson, D. Attwood and J. A. Liddle, "New Nanofabrication Technique Using Overlay for 15-nm Zone Plate," *Micromachining Technology for Micro-Optics and Nano-Optics IV*, G. Johnson, G. P. Nordin and T. J. Suleski Eds., Proc. SPIE **6110**, p. 61100D (2006).
15. G. Vaschenko, A. Garcia Etxarri, C.S. Menoni, J.J. Rocca, O. Hemberg, S. Bloom, W. Chao, E.H. Anderson, D.T. Attwood, Y. Lu and B. Parkinson" Nanometer-scale Ablation with a Table-top Soft X-ray Laser," Opt. Lett., **31**, 3615-3617 (2006).
16. P. Fischer, D. H. Kim, B. Kang, W. Chao and E. H. Anderson, "Magnetic Microstructures and Their Dynamics Studied by X-Ray Microscopy," Micron **37**, 296 (2006).
17. D. Kim, P. Fischer, W. Chao, E. Anderson, S. Choe, M. Im and S. Shin, "Magnetic Soft X-Ray Microscopy at 15nm Resolution Probing Nanoscale Local Magnetic Hysteresis," J. Appl. Phys., **99**, 08H303 (2006).
18. G. Vaschenko, C. Brewer, F. Brizuela, Y. Wang, M.A. Larotonda, B.M. Luther, M.C. Marconi, J.J. Rocca, C.S. Menoni, E.H. Anderson, W. Chao, B.D. Harteneck, J.A. Liddle, Y. Liu and D.T. Attwood, "Sub-38 nm Resolution Tabletop Microscopy with 13 nm Wavelength Laser Light," Opt. Lett., **31**, 1214-1216 (2006).
19. G. Vaschenko, F. Brizuela, C. Brewer, M.A. Larotonda, Y. Wang, B.M. Luther, M.C. Marconi, J.J. Rocca, C.S. Menoni, W. Chao, E.H. Anderson, Y. Liu and D.T. Attwood, " EUV imaging with a 13nm tabletop laser reaches sub-38nm spatial resolution," *Emerging Lithographic Technologies X*, M. J. Lercel, ed., Proc. SPIE **6151**, 61510X (2006).
20. D. Attwood, W. Chao, E. Anderson, J. A. Liddle, B. Harteneck, P. Fischer, G. Schneider, M. L. Gros and C. Larabell, "Imaging at High Spatial Resolution: Soft X-Ray Microscopy to 15 nm," J. Biomed. Nanotech., **2**, 75-78 (2006).

2005

21. W. Chao, B.D. Harteneck, J.A. Liddle, E.H. Anderson and D.T. Attwood, "Soft X-ray Microscopy at a Spatial Resolution better than 15 nm," *Nature*, **435**, 1210-12 13 (2005).
22. F. Brizuela, G. Vaschenko, C. Brewer, M. Grisham, C.S. Menoni, M.C. Marconi, J.J. Rocca, W. Chao, J.A. Liddle, E.H. Anderson, D.T. Attwood, A.V. Vinogradov, I.A. Artioukov, Y.P. Pershyn and V.V. Kondratenko, "Reflection Mode Imaging with Nanoscale Resolution Using a Compact Extreme Ultraviolet Laser," *Opt. Express*, **13**, 3983-3988 (2005).
23. G. Vaschenko, F. Brizuela, C. Brewer, M. Grisham, H. Mancini, C.S. Menoni, M.C. Marconi, J.J. Rocca, W. Chao, J.A. Liddle, E.H. Anderson, D.T. Attwood, A.V. Vinogradov, I.A. Artioukov, Y.P. Pershyn and V.V. Kondratenko, " Nanoimaging with a Compact Extreme Ultraviolet Laser," *Opt. Lett.*, **30**, 2095-2097 (2005).
24. D. Kim, B. Kang, W. Chao, P. Fischer, E. Anderson, S. Choe, M. Im, and S. Shin, "Direct Spatial-temporal Observation of Barkhausen Avalanche in Low-dimensional Ferromagnetic System," *Fluctuations and Noise in Materials II*, P. Svedlindh, ed., Proc. SPIE **5843**, 40-51 (2005).

2003

25. Doran, A. Scholl, J. Feng, W. Chao, E. Anderson and H. Padmore, "Comprehensive Electron-Optical Characterization of an X-Ray Photoemission Electron Microscope," *Synchrotron Radiation Instrumentation*, T. Warwick, J. Arthur, H. Padmore, and J. Stohr, eds., AIP, **705**, 1279-1282 (2004).
26. G. Denbeaux, P. Fischer, G. Schneider, J.A. Liddle, E. Anderson, A. Pearson, W. Chao, C. Larabell, M. Le Gros and D. Attwood, "Full-field Soft X-ray Microscopy at the Advanced Light Source," *Synchrotron Radiat. News* **16**(3), 16-22 (2003).
27. G. Denbeaux, E. Anderson, B. Bates, W. Chao, J.A. Liddle, B. Harteneck, A. Pearson, F. Salmassi, G. Schneider, P. Fischer, T. Eimuller, S. Taylor, H. Chang and G.J. Kusinski, "X-ray Magnetic Microscopy for Correlations between Magnetic Domains and Crystal Structure," *J. de Physique IV*, **104**, 477-81 (2003).
28. W. Chao, E. Anderson, G. Denbeaux, B. Harteneck, J.A. Liddle, D. Olynick, A.L. Pearson, F. Salmassi, C. Song and D. Attwood, "20-nm-resolution Soft X-ray Microscopy Demonstrated Using Multilayer Test Structures," *Opt. Lett.* **28**, 2019-2021 (2003).
29. W. Chao, E. Anderson, G. Denbeaux, B. Harteneck, J.A. Liddle, D. Olynick, A.L. Pearson, F. Salmassi, C. Song and D. Attwood, "Demonstration of 20 nm half-pitch Spatial Resolution with Soft X-ray microscopy," *J. Vac. Sci. Techn. B* **21**, 3108-3111 (2003).

2001

30. W. Chao, E. H. Anderson, G. Denbeaux, B. Harteneck, A. L. Pearson, D. Olynick, G. Schneider and D. Attwood, "Experimental Analysis of High-Resolution Soft X-ray Microscopy," *X-ray Micro- and Nano-Focusing: Applications and Techniques II*, I. McNulty, eds., Proc. SPIE **4499**, 134-141 (2001).
31. W. Chao, E. Gullikson and D. Attwood, "Equivalent Multilayer Bandwidth and Comparisons between 13.4 nm and 14.4 nm for EUV Throughput Calculation," *Emerging Lithographic Technologies V*, E. A. Dobisz, eds., Proc. SPIE **4343**, 676-683 (2001).
32. E. H. Anderson, D. L. Olynick, W. Chao, B. Harteneck and E. Veklerov, "Influence of sub-100 nm Scattering on High-energy Electron Beam Lithography," *J. Vac. Sci. Techn. B* **19**, 2504-2507 (2001).
33. G. Denbeaux, E. Anderson, W. Chao, T. Eimüller, L. Johnson, M. Köhler, C. Larabell, M. Le Gros, P. Fischer, A. Pearson, G. Schütz, D. Yager and D. Attwood, "Soft X-Ray Microscopy to 25 nm with Applications to Biology and Magnetic Materials," *Nucl. Instrum. Methods Phys. Res. A*, **467-468**, 841-844 (2001).

2000

34. W. Chao, E. Anderson, G. Denbeaux, B. Harteneck, M. Le Gros, A. L. Pearson, D. Olynick and D. Attwood, "High Resolution Soft X-ray Microscopy," *Soft X-Ray and EUV Imaging Systems*, W. M. Kaiser and R. H. Stulen, eds., Proc. SPIE **4146**, 171-175 (2000).
35. E. H. Anderson, D. L. Olynick, B. Harteneck, E. Veklerov, G. Denbeaux, W. Chao, A. Lucero, L. Johnson and D. Attwood Jr., "Nanofabrication and Diffractive Optics For High-Resolution X-Ray Applications," *J. Vac. Sci Technol. B* **18**, 2970-2975 (2000).
36. Pearson, W. Chao, G. Denbeaux, T. Eimüller, P. Fischer, L. Johnson, M. Köhler, C. Larabell, M. Le Gros, D. Yager and D. Attwood, "XM-1, the High Resolution Soft X-ray Microscope at the Advanced Light Source," *Soft X-Ray and EUV Imaging Systems*, W. M. Kaiser and R. H. Stulen, eds., Proc. SPIE **4146**, 54-59 (2000).